

Analysis & Design of a Closed-Loop Converter-Controlled DC Drive

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Abstract- This paper describes the speed control of DC drive using closed loop control method. In DC drive Armature voltage control is preferred because of high efficiency and good speed regulation. But it can provide speed control only below base (rated) speed because the armature voltage cannot be allowed to exceed rated value. For speed control above base speed, field flux control is employed. In a separately excited motor, flux is controlled by varying voltage across field winding. The thyristor D.C. drive remains an important speed-controlled industrial drive, especially where the higher maintenance cost associated with the D.C. motor brushes is tolerable. The controlled (thyristor) rectifier provides a low-impedance adjustable 'D.C.' voltage for the motor armature, thereby providing speed control.

Keywords- DC Drive, Closed loop method, Thyristor converter

I. INTRODUCTION

The thyristor D.C. drive remains an important speed-controlled industrial drive, especially where the higher maintenance cost associated with the D.C. motor brushes is tolerable. The controlled (thyristor) rectifier provides a low-impedance adjustable 'D.C.' voltage for the motor armature, thereby providing speed control.

The motor/generator (MG) set could be sited remote from the D.C. motor, and multi-drive sites (e.g. steelworks) would have large rooms full of MG sets, one for each variable-speed motor on the plant. Three machines (all of the same power rating) were required for each of these 'Ward Leonard' drives, which was good business for the motor manufacturer. For a brief period in the 1950s they were superseded by grid-controlled mercury arc rectifiers, but these were soon replaced by thyristor converters which covered cheaper first cost, higher efficiency (typically over 95%), smaller size,

reduced maintenance, and faster response to changes in set speed. The first and major part of this paper is devoted to thyristor-fed drives, after which we will look briefly at chopper-fed drives that are used mainly in medium and small sizes, and finally turn attention to small servo-type drives.

II. THYRISTOR D.C. DRIVES

For motors up to a few kilowatts the armature converter can be supplied from either single-phase or three-phase mains, but for larger motors three-phase is always used. A separate thyristor or diode rectifier is used to supply the field of the motor: the power is much less than the armature power, so the supply is often single-phase, as shown in Figure a.

The arrangement shown in Figure a. is typical of the majority of D.C. drives and provides for closed-loop speed control. The function of the two control loops will be explored later, but readers who are not familiar with the basics of feedback and closed-loop systems may find it helpful to read through the Appendix at this point.

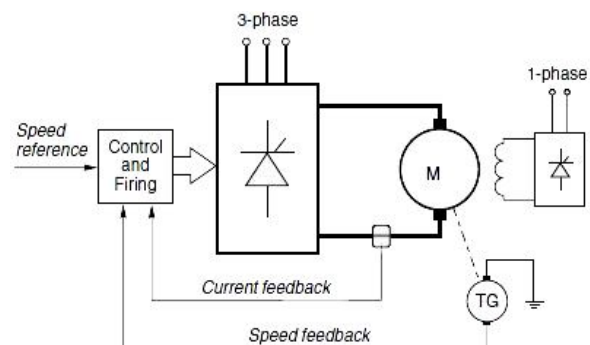


Fig a Schematic diagram of speed-controlled D.C. motor drive

The main power circuit consists of a six-thyristor bridge circuit which rectifies the incoming A.C. supply to produce a D.C. supply to the motor armature. The assembly of thyristors, mounted on a heatsink, is usually referred to as the 'stack'. By altering the firing angle of the thyristors the mean value of the rectified voltage can be varied, thereby allowing the motor speed to be controlled. The controlled rectifier produces a crude form of D.C. with a pronounced ripple in the output voltage. This ripple component gives rise to pulsating currents and fluxes in the motor, and in order to avoid excessive eddy-current losses and commutation problems, the poles and frame should be of laminated construction. It is accepted practice for motors supplied for use with thyristor drives to have laminated construction, but older motors often have solid poles and/or frames, and these will not always work satisfactorily with a rectifier supply. It is also the norm for drive motors to be supplied with an attached 'blower' motor as standard. This provides continuous through ventilation and allows the motor to operate continuously at full torque even down to the lowest speeds without overheating.

The combination of power, control, and protective circuits constitutes the converter. Standard modular converters are available as off-the-shelf items in sizes from 0.5 kW up to several hundred kW, while larger drives will be tailored to individual requirements. Individual converters may be mounted in enclosures with isolators, fuses etc., or groups of converters may be mounted together to form a multi-motor drive.

III. CLOSED-LOOP CONTROL OF DRIVES

Feedback loops in an electrical drive may be provided to satisfy one or more of the following requirements:

- (i) Protection
- (ii) Enhancement of speed of response
- (iii) To improve steady-state accuracy

This section describes various closed-loop configurations which find application in electric drives. In all these schemes the converter and associated control circuit will be represented by a single block marked converter.

A Closed-Loop Speed control

Closed-loop speed control scheme which is widely used in electrical drives. It employs an inner current control loop within an outer speed-loop. Inner current control loop is provided to limit the converter and motor current or motor torque below a safe limit. In some schemes the current is controlled directly. In others it may be controlled indirectly. For example, in a variable frequency induction motor drives the current is controlled by controlling the slip. Inner current loop is also beneficial in reducing the effect on drive performance of any non-linearity present in converter-motor system.

An increase in reference speed produces a positive error. Speed error is processed through a speed controller and applied to a current limiter which saturates even for a small speed error. Consequently, limiter sets current reference for inner current control loop at a value corresponding to the maximum allowable current. Drive accelerates at the maximum allowable current (and in some cases at the maximum torque). When close to the desired speed, limiter desaturates. Steady-state is reached at the desired speed (with some steady-state error) and at current for which motor torque is equal to the load torque. A decrease in reference speed produces a negative speed error. Current limiter saturates and sets current reference for inner current loop at a value corresponding to the maximum allowable current. Consequently, drive decelerates in braking mode at the maximum allowable current. When close to the required speed, current limiter desaturates. The operation is transferred from braking to motoring. Drive then settles at a desired speed and at current for which motor torque equals the load torque. In those drives where the current does not have to reverse for braking operation, current limiter will have the input-output characteristics. In those drive applications where the load torque is able to provide enough decelerating torque, electric braking need not be used. Then also current limiter has the characteristic.

Current and speed controller may consists of proportional and integral (PI), proportional and derivative (PD) or proportional, integral and derivative (PID) controller, depending on steady-state accuracy and transient response requirements. DC drives are widely used in application requiring adjustable speed, good speed regulation and frequent starting, braking and reversing. Some important application are rolling mills, paper mills, mine winders, hoists, machine tools, traction, printing presses, textile mills, excavators and cranes. Fractional horsepower dc motors are widely used as servo motors are widely used as servo motors for positioning and tracing.

IV. DC DRIVE

A. Description

Series 6RA70 SIMOREG DC MASTER converters are fully digital, compact units for three-phase-supply which supply the armature and field of variable-speed DC drives with rated armature currents of between 15A and 3000A. The compact converters can be connected in parallel to supply currents of up to 12000A. The field circuit can be supplied with currents of up to 85A (current levels depend on the armature rated current).

B. Design

Series 6RA70 SIMOREG DC MASTER converters are characterized by their compact, space saving construction. Their compact design makes them particularly easy to service and maintain since individual components are readily

accessible. The electronics box contains the basic electronic circuitry as well as any supplementary boards.

All SIMOREG DC MASTER units are equipped with a PMU simple operator panel mounted in the converter door. The panel consists of a five-digit, seven-segment display, three LEDs as status indicators and three parameterization keys. The PMU also features connector X300 with a USS interface in accordance with the RS232 or RS485 standard. The panel provides all the facilities for making adjustments or settings and displaying measured values required to start up the converter.

The OP1S optional converter operator panel can be mounted either in the converter door or externally, e.g. in the cubicle door. For this purpose, it can be connected up by means of a 5 m long cable. Cables of up to 200 m in length can be used if a separate 5 V supply is available. The OP1S is connected to the SIMOREG via connector X300. The OP1S can be installed as an economic alternative to control cubicle measuring instruments which display physical measured quantities. The OP1S features an LCD with 4 x 16 characters for displaying parameter names in plaintext. German, English, French, Spanish and Italian can be selected as the display languages. The OP1S can store parameter sets for easy downloading to other devices. The converter can also be parameterized on a standard PC with appropriate software connected to the serial interface on the basic unit. This PC interface is used during start-up, for maintenance during shutdown and for diagnosis in operation. Furthermore, converter software upgrades can be loaded via this interface for storage in a Flash memory. On single-quadrant converters, the armature is supplied via a fully controlled three-phase bridge B6C and, on four-quadrant devices, via two fully controlled three-phase bridges in circulating current- free, inverse-parallel connection (B6)A(B6)C. The field is supplied via a single-phase, branch-pair half-controlled 2-pulse bridge connection B2HZ. The frequencies of the armature and field supply voltages may be different (in a range from 45 to 65 Hz). Operation in the extended frequency range between 23 Hz and 110 Hz is available on request. The armature circuit supply phase sequence is insignificant. For converters with 15A to 850A (1200A at 400V supply voltage) rated DC current, the power section for armature and field is constructed of isolated thyristor modules. The heat sink is thus electrically isolated. On devices with a higher rated DC current, the power section for the armature circuit is constructed of disk thyristors and heat sinks (thyristor assemblies) at voltage potential. The housing and terminal covers on power connections provide protection against accidental contact for operators working in the vicinity. All connecting terminals are accessible from the front. The power section cooling system is monitored by means of temperature sensors.

C. Simoreg Dc Master Operating Instructions

Special features of devices with 460V rated connection voltage

- This device series is available with rated direct currents of 30A to 1200A.
- Devices with rated direct currents of 450A to 1200A are equipped with a 1-phase fan.
- On devices with rated direct currents of 60A to 850A, the power terminals are located on the underside and on the top of the device.

D. Installation Of Simoreg Devices In Cabinets In Accordance With Ul 508 C Standards

- When the drive is provided in a panel (enclosure), the panel is ventilated and designated "Type 1".
- The minimum size panel (enclosure) to be used with the drive is 600 mm length, 600 mm width, 2200 mm height.

V. MODE OF OPERATION

All open-loop and closed-loop drive control and communication functions are performed by two powerful microprocessors. Drive control functions are implemented in the software as program modules which can be "wired up" by parameters. The rated DC currents (continuous DC currents), load class I, specified on the rated plate can be exceeded by 180%, the permissible overload during being dependent on individual converters. The microprocessor calculates the current I_{2t} value of the power section cyclically to ensure that the thyristors are not damaged in overload operation. A selection table for overload operation can be found in Section 9 "Description of functions". Converters self-adapt to the frequency of the available supply voltage in the range from 45 to 65 Hz (armature and field are independent). Operation in the extended frequency range between 23 Hz and 110 Hz is available on request.

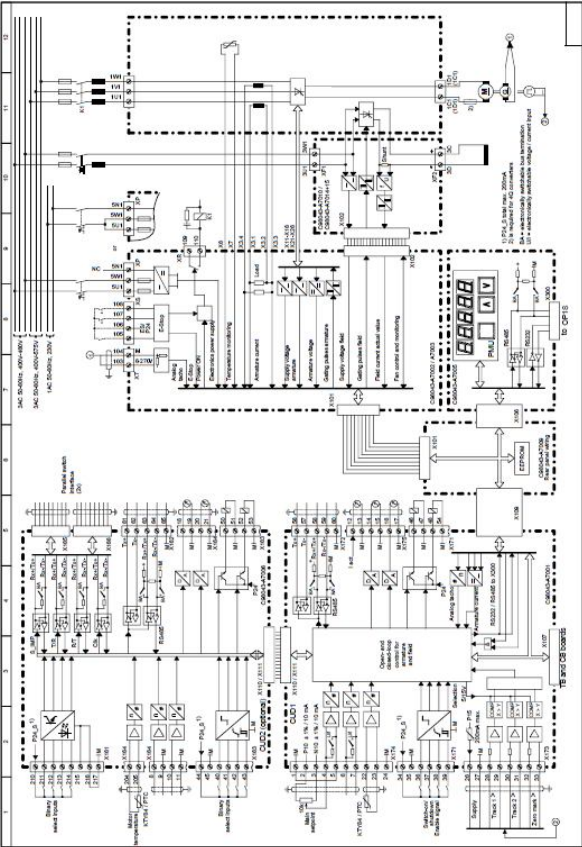


Fig.1 Block Diagram With Recommended Connection

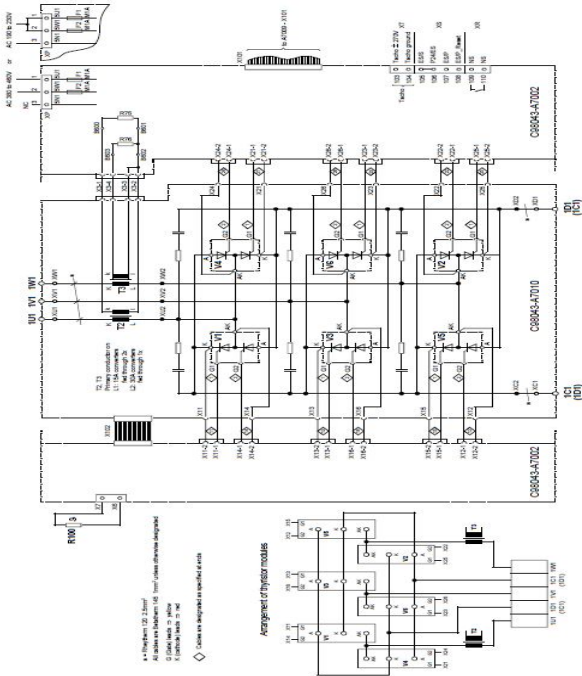


Fig. 2 Armature Converter Circuit

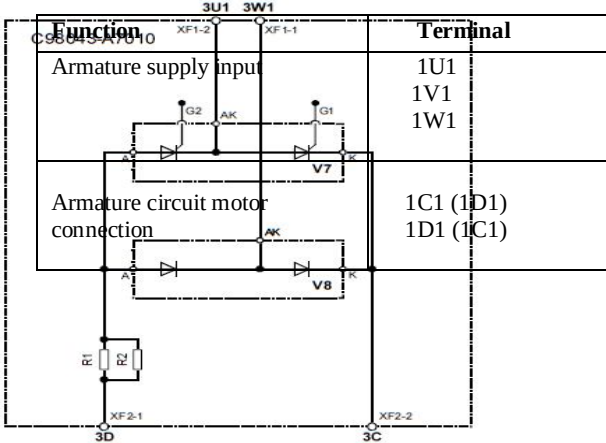


Fig. 3 Field Supply Converter

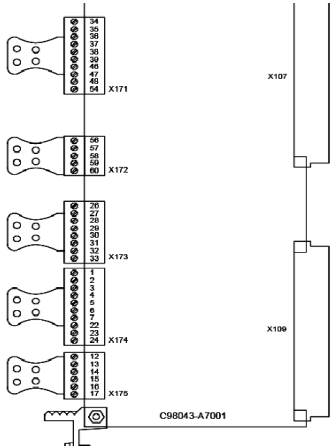
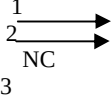


Fig.4 Description of drive terminals
Table-1 Armature circuit

Table-2 Field circuit

Function	Terminal	Connection values/Remarks
Supply connection	XF1-2 3U1 XF1-1 3W1	2AC 400V (- 20%), 2AC 460V (+10%) Rated DC voltage 325V / 373V
Field winding connection	XF2-2 3C XF2-1 3D	For 2AC 400V / 460V supply connection

Table-3 Electronics power supply

Function	connection	Terminal XP	Connection values/Remarks
Incoming supply 400V		5U1 5W1 5N1	2AC 380V (– 25%) to 460V (+15%); In=1A(– 35% for 1min)

Function	Terminal XT	Connection values/Remarks
Supply (output)	34	24V DC, short circuit proof
Ground digital M	35	max. load 200mA (terminals 34, 44, and 210 combined), internal supply with respect to internal ground Overload response: Error signal F018 Warning signal A018
Select input binary 1 Power On / Shutdown H signal: Power ON Line contactor CLOSED + (with H signal at terminal 38), acceleration along ramp function generator ramp to operating speed. L signal: Shutdown Deceleration along ramp function generator ramp to $n < n_{min}$ (P370) + , controller disable + line contactor OPEN.	36 37	H signal: +13V to +33V L signal: – 33V to +3V or terminal open 8.5mA at 24V
Enable operation H signal: Controller enabled L signal: Controller disabled See Section 9.3.4 for exact function description Select input binary 2	38 39	H signal: +13V to +33V L signal: – 33V to +3V or terminal open 8.5mA at 24V

Function	Terminal XT	Connection values/Remarks
Tacho connection 8V to 270V Ground analog M	103 104	$\pm 270V$; $>143k\Omega$

Table-4
Analog inputs – set point inputs, reference voltage

Function	Terminal X174	Connection values/Remarks
Reference M P10 N10	1 2 3	$\pm 1\%$ at 25°C (stability 0.1% per 10°K); 10mA shortcircuit-proof
Select input main setpoint + main setpoint – Select input analog 1 + analog 1 –	4 5 6 7	Input type (signal type) parameterizable: - Differential input $\pm 10V$; 150k Ω - Current input 0 - 20mA; 300 Ω or 4 - 20mA; 300 Ω Resolution can be parameterized up to approx. 555 μV (± 14 bit) Common mode suppression: $\pm 15V$

Table-5 Analog inputs - actual speed inputs, tachometer inputs

Table-6 Binary control inputs

VI. SIMPLE OPERATOR CONTROL PANEL (PMU “PARAMETERIZATION UNIT“)

The simple operator control panel is mounted in the converter door and consists of a 5-digit, 7-segment display with three status display LEDs and three parameterization keys below. All adjustments and settings that need to be undertaken for the purpose of start-up can be made on the simple control panel.

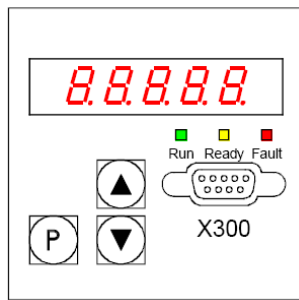


Fig.5 Parameterization Unit

A. LED Display

Run green LED	
LED illuminated	In "Torque direction active" state.
Ready yellow LED	
LED illuminated	In "Ready" state.
Fault red LED	
LED illuminated ⇒	In "Fault signal present" .
LED flashing ⇒	An alarm is active.

VII. WIRING DIAGRAM

A. DRIVE PANEL

3 AC 50 Hz 440V is given to Input terminal of drive 1U1, 1V1 and 1W1. This is input of dual-converter. Output is taken from terminal 1C1 (1D1) and 1D1 (1C1) which is given to motor armature terminals with suitable measuring instruments. 2 AC 50 Hz 440 V is given to Terminal 3U1 and 3W1 this is input of semi-converter used by drive and output is taken out from terminals 3D and 3C which is given to motor field windings. 5U1 and 5W1 is fed with 2 AC 50 Hz 440V this is power electronic supply of drive.

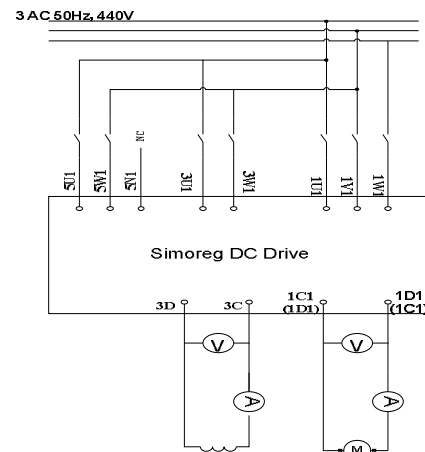


Fig. 6 Drive Connection

B. Complete Setup

Fig.7 shows the complete setup of Simoreg DC drive connecting with DC motor with suitable measuring instruments

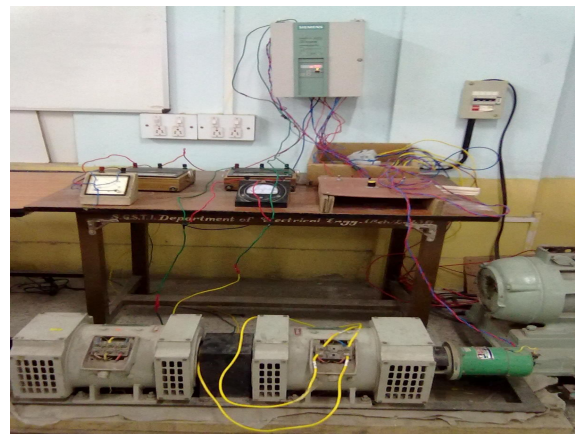


Fig.7 Complete Setup

VIII CONCLUSION

Armature voltage control is preferred because of high efficiency and good speed regulation. But it can provide speed control only below base (rated) speed because the armature voltage cannot be allowed to exceed rated value. For speed control above base speed, field flux control is employed. In a separately excited motor, flux is controlled by varying voltage across field winding.

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